Appl: 09/771,366

[0076] An etalon **60** is included in the line-narrowing module of **FIG. 7**. The etalon **60** is within an enclosure **61** together with the prism **59** and the grating **35** which is attached to the heat sink **38**. The positions of the etalon **60** and prism **59** may be switched, and preferably are, for higher repetition rate laser operation as explained above with reference to **FIGS.** *5a* and *5b*.

[0077] The pressure within the enclosure **61** is varied to tune and/or select the wavelength using over- or under-pressure, and either filled with stagnant gas using no purging gas flow, or using a flowing gas and a continuous gas flow. When no flow is used, then preferably only the port **62** is hooked up to a pump or a pressurized gas bottle, e.g., through a pressure regulator. When continuous flow is used, then each of ports **62** and **64** is used, one as an inlet **62** and the other as an outlet **64**, wherein the outlet **64** may or may not be connected to a pump. Preferably, a valve or series of valves is used to control the pressure, and the pump, if used, may have variable speeds.

[0078] The etalon **60** and the grating **35** are each preferably initially aligned at selected angles to the beam depending on the desired wavelength range to be used, and then the pressure in the enclosure **61** is varied to tune the wavelength around that initially selected wavelength. The etalon **60** or both the etalon **60** and the prism **59** may alternatively be outside the enclosure **52**.

[0079] **FIG. 8** schematically shows a line-narrowing module in accord with a seventh embodiment. The line-narrowing module of **FIG. 8** is preferably the same as the fourth embodiment described with reference to **FIG. 7**, except there is no enclosure **61** and the etalon **60** is replaced by the etalon **68** and/or the prism **59** is replaced with the prism **66**. The etalon **68** differs from the etalon **60** in that the etalon **68** is preferably rotatable for tuning the wavelength output by the line-narrowing module. Alternatively, the prism **66** may differ from the prism **59** in that the prism **66** may be rotatable or tuning the wavelength. The etalon **60** and/or prism **59** of the sixth embodiment of **FIG. 7** could also be alternatively rotatable, but preferably the etalon **60** and prism **59** are fixed at the initially selected angles, as discussed above. The other prisms **30, 31** may be additionally or alternatively rotatable, and may be synchronously rotatable as set forth at the 09/244,554 application, incorporated by reference above.

[0080] Since there is no enclosure **61** for tuning the wavelength in the seventh embodiment, and once again the grating **35** is fixed to the heat sink **38**, then the rotatable property of the etalon **68** or prism **66** is advantageous for tuning the wavelength and/or stabilizing the wavelength, e.g., in a feedback loop with a processor and wavelength detector of the diagnostic module **18**.

[0081] The above objects of the invention have been met. Several embodiments of a line-narrowing module for a precision-tunable excimer laser have been described (as well as many further variations discussed above). The bulky grating **35** may remain fixed in position while the wavelength is precisely tuned by finely adjusting the pressure in the enclosures **40, 44**, or by rotating one or more of the prisms **30-32, 48** and/or an etalon **58, 68**.

[0082] A line-narrowing module particularly for a high repetition rate excimer laser having a thermally stabilized diffraction grating has also been described. By attaching the grating **35** to the heat sink, the heat that may otherwise degrade the performance and/or structure of the grating **35** is advantageously dissipated in the heat sink **38**.

[0083] Those skilled in the art will appreciate that the just-disclosed preferred embodiments are subject to numerous adaptations and modifications without departing from the scope and spirit of the invention. Therefore, it is to be understood that, within the scope and spirit of the invention, the invention may be practiced other than as specifically described above. In particular, the invention is to be interpreted in accordance with the appended claims, and equivalents thereof, without limitations being read from the specification above.

[0084] For example, the advantages of pressure-tuning using the enclosures **40, 44** or tuning the wavelength by rotating one or more of the prisms **30-33, 48** may be realized without attaching the grating **35** to the heat sink **38**. Moreover, the enclosure may seal different elements of the line-narrowing module. For example, the enclosure may seal one or more of the prisms **3033, 48** and/or an etalon without sealing the grating **35**. Also, the advantages of attaching the grating **35** to the heat sink **38** may be realized while still rotating the grating **35** along with the heat sink **38** to tune the wavelength. In addition, the enclosure **40, 44** may be advantageously prepared such as is described at U.S. patent application Ser. No. 09/343,333 free of VUV absorbing species, particularly for an F_2 laser, or even an ArF laser.

What is claimed is:

1. An excimer or molecular fluorine laser, comprising:

a discharge chamber filled with a gas mixture including molecular fluorine;

a plurality of electrodes within the discharge chamber connected to a pulsed discharge circuit for energizing the gas mixture; and

a resonator for generating a laser beam including a pair of resonator reflector surfaces, the discharge chamber and a line-narrowing module,

wherein the line-narrowing module includes:

a beam expander including one or more optical elements for expanding the beam and reducing a divergence of the beam; and

a reflection grating coupled with a heat sink, said grating for receiving the expanded beam and dispersing the beam to reduce a bandwidth of the beam that remains within an acceptance angle of the resonator upon dispersion by the grating, said heat sink for removing heat caused by beam absorption.

2. The laser of claim 1, further comprising one or more interferometric devices for further improving a spectral purity of the beam.

3. The laser of claim 2, wherein at least one of the one or more interferometric devices is rotatable for tuning the wavelength output by the line-narrowing module.

4. The laser of claim 1, wherein the beam expander includes one or more prisms.

5. The laser of claim 4, wherein at least one of the one or more prisms is rotatable for tuning the wavelength output by the line-narrowing module.

6. The laser of claim 4, wherein at least two of the prisms are synchronously rotatable for tuning the wavelength out-

put by the line narrowing module, and for mutually compensating a re-directing of the beam path produced by rotation of said prisms.

7. The laser of claim 1, further comprising a sealed enclosure around one or more optical elements of the line-narrowing module and a processor for monitoring the wavelength of the beam, and wherein the sealed enclosure includes an inert gas inlet for filling the enclosure with an inert gas, the processor further for controlling the pressure of the inert gas within the enclosure for tuning the wavelength output by the line-narrowing module.

8. The laser of claim 7, wherein the enclosure further includes an outlet for flowing an inert gas through said enclosure.

9. The laser of any of claims **7** or **8**, wherein the grating is within the enclosure.

10. The laser of claim 9, wherein the beam expander includes one or more elements disposed within the enclosure.

11. The laser of claim 9, wherein the line-narrowing module further includes one or more interferometric devices.

12. The laser of claim 11, wherein at least one of the one or more interferometric devices is within the enclosure.

13. The laser of any of claims **7** or **8**, wherein the line-narrowing module further includes one or more interferometric devices within the enclosure.

14. The laser of any of claims **7** or **8**, wherein the line-narrowing module further includes one or more elements of the beam expander within the enclosure.

15. An excimer or molecular fluorine laser, comprising:

a discharge chamber filled with a gas mixture including molecular fluorine;

a plurality of electrodes within the discharge chamber connected to a pulsed discharge circuit for energizing the gas mixture; and

a resonator for generating a laser beam including a pair of resonator reflector surfaces, the discharge chamber and a line-narrowing module including one or more optical elements for reducing the bandwidth of the beam,

a sealed enclosure around one or more optical elements of the line-narrowing module; and

a processor for monitoring the wavelength of the beam, and wherein the sealed enclosure includes an inert gas inlet for filling the enclosure with an inert gas, the processor further for controlling the pressure of the inert gas within the enclosure for tuning the wavelength output by the line-narrowing module.

16. The laser of claim 15, wherein the enclosure further includes an outlet for flowing an inert gas through said enclosure.

17. The laser of any of claims **15** or **16**, wherein the line-narrowing module includes:

a beam expander including one or more optical elements for expanding the beam and reducing a divergence of the beam; and

a reflection grating for receiving the expanded beam and dispersing the beam to reduce a bandwidth of the beam that remains within an acceptance angle of the resonator upon dispersion by the grating.

18. The laser of claim 17, wherein the grating is within the enclosure.

19. The laser of claim 18, wherein at least one of the one or more optical elements of the beam expander is also within the enclosure.

20. The laser of claim 18, wherein the line-narrowing module further includes one or more interferometric devices within the enclosure.

21. The laser of claim 17, wherein the line-narrowing module further includes one or more interferometric devices within the enclosure.

22. The laser of claim 16, wherein the processor controls the pressure within the enclosure by controlling a rate of flow of said inert gas.

23. The laser of any of claims **1**, **15** or **16**, further comprising an output coupling interferometer including at least one curved inner surface such a gap spacing between said curved surface and an opposing inner surface varies over a cross section of the interferoemter for further improving a spectral purity of the beam.

24. The laser of claim 23, wherein said opposing inner surface is a substantially flat surface.

25. The laser of claim 23, wherein said opposing inner surface is curved surface, wherein said two inner surfaces having opposing curvatures.

26. The laser of claim 23, wherein said laser is an ArF laser emitting at a wavelength of 193 nm.

26. The laser of any of claims **1**, **15** or **16**, further comprising an etalon output coupler for further improving a spectral purity of the beam.

27. The laser of any of claims **1**, **15** or **16**, wherein the laser is a molecular fluorine laser emitting around 157 nm.

28. The laser of any of claims **1**, **15** or **16**, wherein the laser is an ArF laser emitting around 193 nm.

29. The laser of any of claims **1**, **15** or **16**, wherein the laser is a KrF laser emitting around 248 nm.

30. The laser of claim 1, wherein the line-narrowing module further includes an interferometric device disposed in front of the grating after the beam expander.

31. The laser of claim 17, wherein the line-narrowing module further includes an interferometric device disposed in front of the grating after the beam expander.

32. An excimer of molecular fluorine laser, comprising:

a discharge chamber filled with a gas mixture including molecular fluorine and a buffer gas;

a plurality of electrodes within the discharge chamber connected to a pulsed discharge circuit for energizing the gas mixture at a repetition rate of more than 2 kHz; and

a resonator for generating a laser beam including a pair of resonator reflector surfaces, the discharge chamber and a line-narrowing module including a beam expander, an interferometric device and a grating for reducing the bandwidth of the beam to less than 0.5 pm,

wherein the beam expander comprises optics formed of a thermally stable material at DUV wavelengths and below and at said repetition rate of more than 2 kHz, said interferometric device comprises a pair of plates formed of said same thermally stable material, and the grating is thermally and mechanically stabilized within the line-narrowing module.

33. The laser of claim 32, wherein said thermally stable material of said optics of said beam expander and of said plates of said interferometric device is selected from the group of materials consisting of CaF_2, MgF_2, LiF and BaF_2.

34. The laser of claim 32, wherein said thermally stable material of said optics of said beam expander and of said plates of said interferometric device is CaF_2.

35. The laser of claim 32, wherein said thermally stable material of said optics of said beam expander and of said plates of said interferometric device is MgF_2.

36. An excimer or molecular fluorine laser, comprising:

a discharge chamber filled with a gas mixture including molecular fluorine;

a plurality of electrodes within the discharge chamber connected to a pulsed discharge circuit for energizing the gas mixture; and

a resonator for generating a laser beam including a pair of resonator reflector surfaces, the discharge chamber and a line-narrowing module including a beam expander, an interferometric device and a grating for reducing the bandwidth of the beam,

wherein the interferometric device is disposed before the grating after the beam expander.

37. The laser of claim 36, wherein the beam expander includes a plurality of prisms each disposed between the interferometric device and the discharge chamber.

38. The laser of claim 36, wherein the beam expander includes at least three prisms each disposed between the interferometric device and the discharge chamber.

39. The laser of any of claims **34-36**, wherein the laser is a KrF laser emitting around 248 nm.

40. An excimer or molecular fluorine laser, comprising:

a discharge chamber filled with a gas mixture including molecular fluorine;

a plurality of electrodes within the discharge chamber connected to a pulsed discharge circuit for energizing the gas mixture;

a resonator for generating a laser beam including a pair of resonator reflector surfaces, the discharge chamber and a line-narrowing module;

a sealed enclosure around one or more optical elements of the line-narrowing module; and

a processor for monitoring the wavelength of the beam, and wherein the sealed enclosure includes an inert gas inlet for filling the enclosure with an inert gas, the processor further for controlling the pressure of the inert gas within the enclosure for tuning the wavelength output by the line-narrowing module,

wherein the line-narrowing module includes:

a beam expander including one or more optical elements for expanding the beam and reducing a divergence of the beam; and

a reflection grating coupled with a heat sink, said grating for receiving the expanded beam and dispersing the beam to reduce a bandwidth of the beam that remains within an acceptance angle of the resonator upon dispersion by the grating, said heat sink for removing heat caused by beam absorption.

41. The laser of claim 40, wherein the enclosure further includes an outlet for flowing an inert gas through said enclosure.

42. The laser of any of claims **1** or **37**, wherein said grating is fixable attached to said heat sink.

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